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Wave Height Measurement by Radar

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13. ABSTRACT

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[redacted] heights have been measured by the use of a slightly modified NRL X-band nanosecond-pulse test radar. This equipment, mounted above the surface and looking down, provided a precision that is equivalent to that obtained from a through-the-surface wave sensor. Stable platforms 20 to 60 feet above the surface gave excellent results, and a brief test made with a helicopter flying 100 feet up at 60 to 100 knots forward speed indicated possibilities for this platform. Targets with a periodic change in range, such as a swinging sphere, have been studied.

The combination of nanosecond radar techniques and fixed platforms for looking vertically at the rough water surface permits wave heights to be measured in the open ocean where through-the-surface sensors are not practical.

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WAVE HEIGHT MEASUREMENT BY RADAR

INTRODUCTION

Knowledge of the open-ocean surface roughness is an important factor in the evaluation of ship and aircraft radar design and testing procedures. This report discusses a method which uses an experimental low-power, X-band radar to determine ocean wave heights when looking vertically at short ranges from above the surface. NRL Memorandum Report 1720* describes the method used in this experimental radar to develop the nanosecond microwave pulses, and NRL Memorandum Report 1870† describes the use of these microwave pulses as transmitter pulses in a low-power, X-band radar. NRL Report 6933‡ follows up with the use of this high-resolution radar at close ranges in the study of backscatter (clutter) from wind-blown capillary waves and from paddle-generated waves. The ability to measure at close ranges permitted a vertical look at the artificial waves as well as low-angle looks. This report indicates the range-measurement capabilities of the nanosecond pulse radar looking vertically at rough water.

EXPERIMENTAL RADAR CHARACTERISTICS

The experimental radar characteristics are as follows:

Frequency: X-band
Pulse power: 10 milliwatts
Pulse length: 1.2 nsec
Horn antenna: 22.9 cm by 15.8 cm
Antenna gain: 24 dB
Beamwidth (3 dB, one-way pattern):
    Horizontal: 10.2°
    Vertical: 11.8°
Prf: 10 kHz.

By carefully selecting the snap-varactor diode and its related drive and tuning circuits, it was possible to get 10 milliwatts pulse power directly for the transmitter without the use of traveling wave tube (TWT) amplifiers. With operating ranges of 100 ft and less, this power was sufficient to insure dropout-free operation on all tests conducted. One of the normal data outputs from a Tektronix sampling scope was modified by added circuitry. Prior usage of this sampling scope used only the scope pictures of normal "A" trace plus the output of the video vertical amplifier to drive the pen recorder for the range-gated mode of operation (no horizontal sweep). To develop an analog signal of the changing range to the illuminated area of the water surface below the antenna, the horizontal sawtooth

*George F. Myers, "Nanosecond X-Band Pulses from Snap Diodes," NRL Memorandum Report 1720, Sept. 1966.
†G.F. Myers, "Nanosecond Pulse Radar as a Measuring Tool," NRL Memorandum Report 1870, May 1968.
‡G.F. Myers and I.W. Fuller, Jr., "Nanosecond Radar Observation of Sea Clutter Cross-Section Versus Grazing Angle," NRL Report 6933, Oct. 1969.

sweep output of the Tektronix scope was combined with the vertical amplifier output (both available on the front panel of this oscilloscope) in a novel circuit.* This analog voltage is used to drive the pen recorder or digital data recorder as needed. Figure 1 is a block diagram of the system.

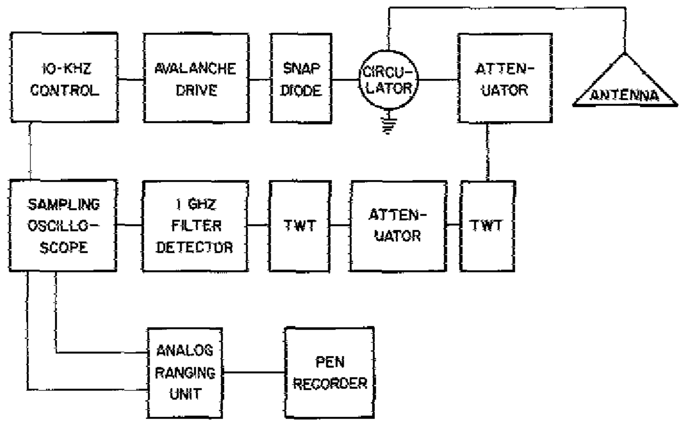


Fig. 1 - Block diagram of the ΔR radar

DISCUSSION OF THE EXPERIMENTS

Swinging Sphere

An experiment was set up to develop and demonstrate the ability of a radar to indicate instantaneous changes in range for a target whose average range change is zero. For purposes of simplicity, this model of the nanosecond pulse test radar is called the "ΔR" radar. A 12-inch metalized sphere was suspended from above into the area illuminated by the antenna out in range a distance of 12 ft. In this position, the sphere was given a motion directed in an arc roughly tangent to the center ray of the antenna beam. Figure 2 shows the 1-nsec echo pulse moving back and forth on the "A" trace (2 nsec per cm, or 1 ft per cm, displacement). The radar analog ranging unit developed for these tests produces the pen recorder record of the same signal as shown in Figure 3.

Wave Tank Tests

The initial wave-height-measurement tests were made on artificially generated waves of known magnitudes and shapes. To make these tests, the experimental radar was set up at the U.S. Army Engineers' wave tank facilities at Washington, D.C. At this location, waves are generated by a movable ram at one end in bursts and travel down the 30-ft-wide tank several hundred feet to the sloping far end built to simulate beach action. If the length of the burst is limited to four or five waves, a study of this set of waves at the center will be free of any serious reflections. Since the installation had a step-wave staff set up at the center, the radar was placed to illuminate the water just ahead of the staff to permit close correlation of radar records with the wave staff records. Figure 4 shows the antennas mounted over the tank, and Figure 5 shows the depth gage used to visually check wave heights as they pass. The radar records of a burst of waves are shown as they were recorded simultaneously with the wave staff output. The staff gage

*Designed by Ralph Curtis of the NRL Engineering Services Division

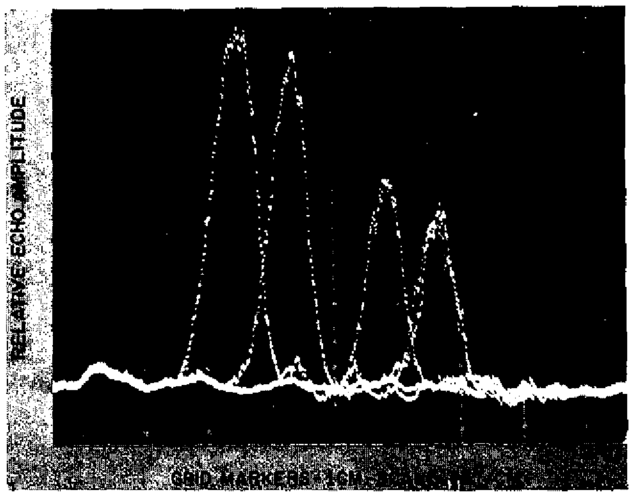


Fig. 2 - "A" scope range displacement using a 12-in. sphere. For this picture four separate single sweeps were iniated with timing selected to show extremes in range as well as two intermediate positions.

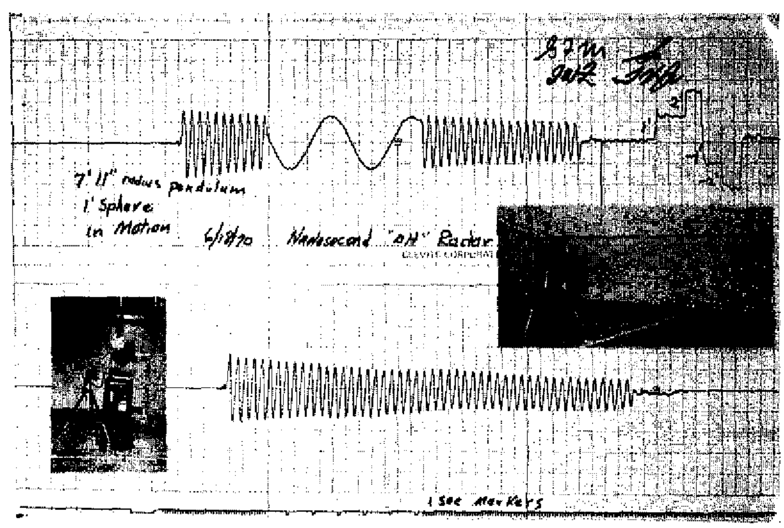


Fig. 3 - ΔR radar. The bottom Brush record shows the response of the radar to the swinging 12-in. metalized sphere shown in the two photographs. The top Brush record has an expanded section of the time base inserted with a series of calibration marks at the right end.

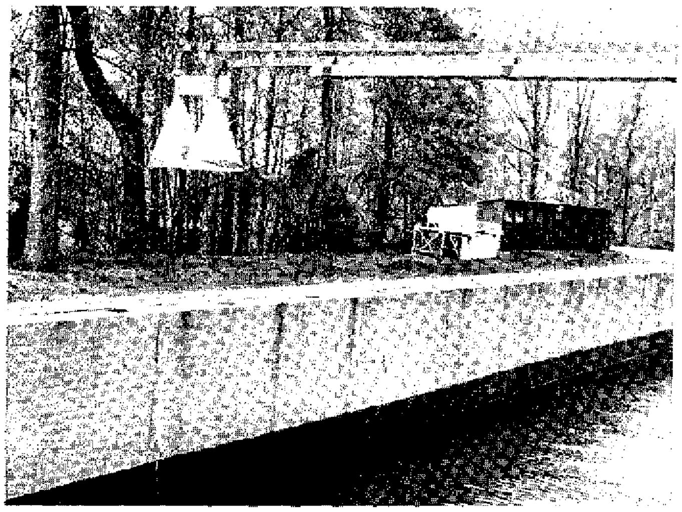


Fig. 4 - U.S. Army Coastal Engineers wave tank; view of antenna installation 18 ft above the water

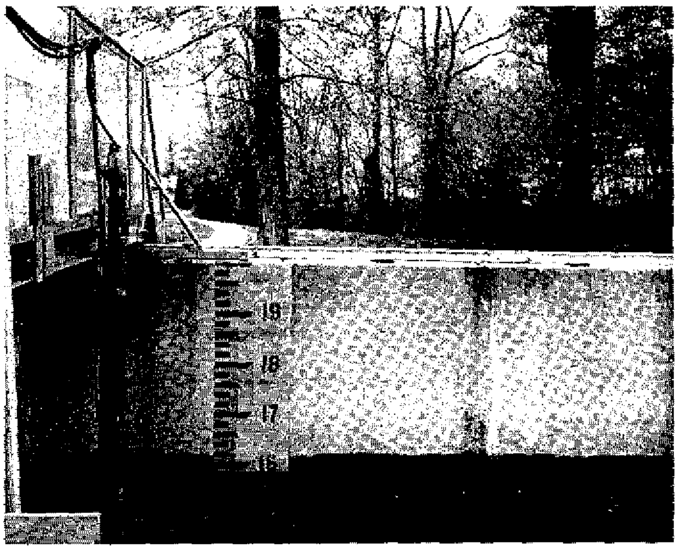


Fig. 5 - U.S. Army Coastal Engineers wave tank; view of depth gage and staff wave gage

is of the step variety with 1-inch steps visible on the record. Separate calibration checks for the radar record indicated it to be accurate to within 1-inch or better as compared with the wave staff record. Figure 6 compares the radar record with the wave staff record.

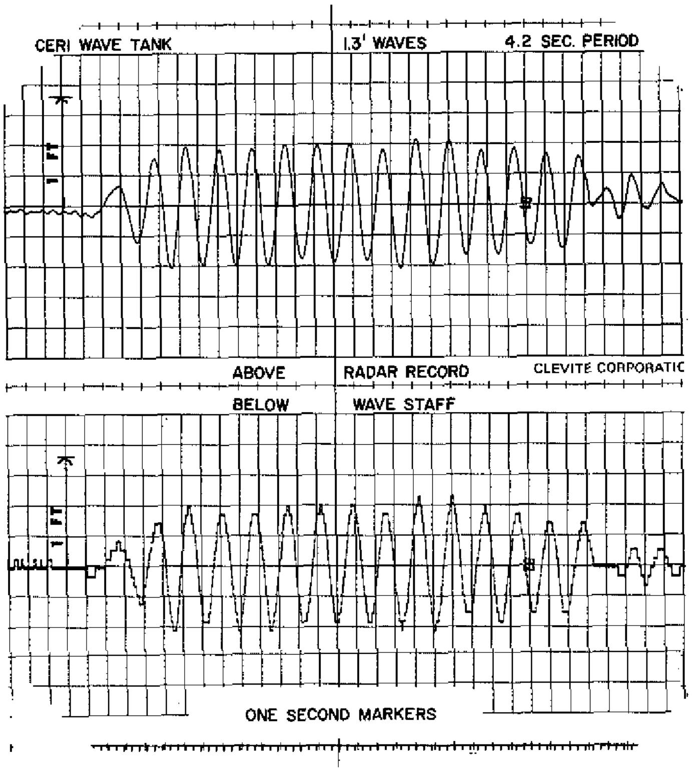


Fig. 6 - Simultaneous comparison of the two gages

Gulf of Mexico Tests

As part of a field trip program at Panama City, Florida, the test radar was operated in the analog-ranging mode to record open-water wave heights in the Gulf of Mexico. Figure 7 shows the tower used and the antenna installation 60 feet above the surface. Again, the antenna was aimed at a patch of water adjacent to a permanently installed wave staff for comparison purposes. Data were recorded this time in both the analog and the digital form, the latter at a rate of up to 50 samples per second. This digital data will be statistically analyzed in the future. Figure 8 shows the analog records taken for 1- to 2-ft waves.

The Base helicopter facilities made available one of their crews and a helicopter for a brief afternoon flight. The test radar was flown at 100-ft elevation, with speeds ranging from 60 to 100 knots per hour. The recorded output contained two combined signals, representing changes in elevation of the helicopter and changes in range due to water roughness. By selecting the proper "lateral speed over the waves," it was possible to obtain a slow-moving curve representing elevation changes modulated by a much more rapidly fluctuating curve representing wave heights. Interpretation of this pattern gave a reasonable measure of the wave heights present during the flight. No effort was made to calibrate the curve obtained in this very brief test due to time constraints but it did

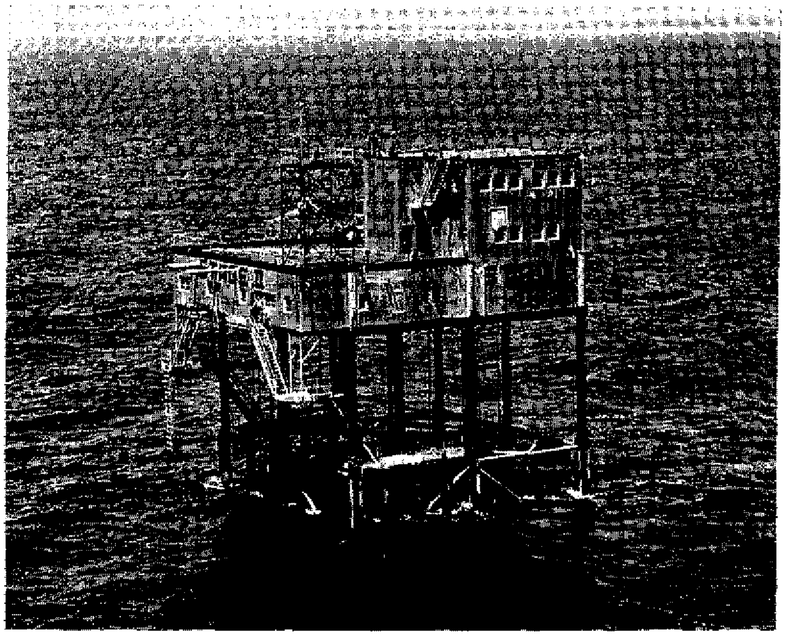


Fig. 7a - Panama City tower, U.S. Naval Ship Research and Development Laboratory

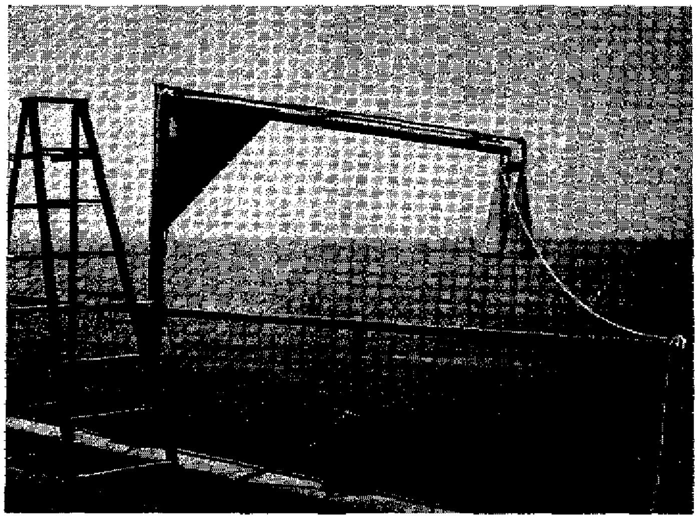
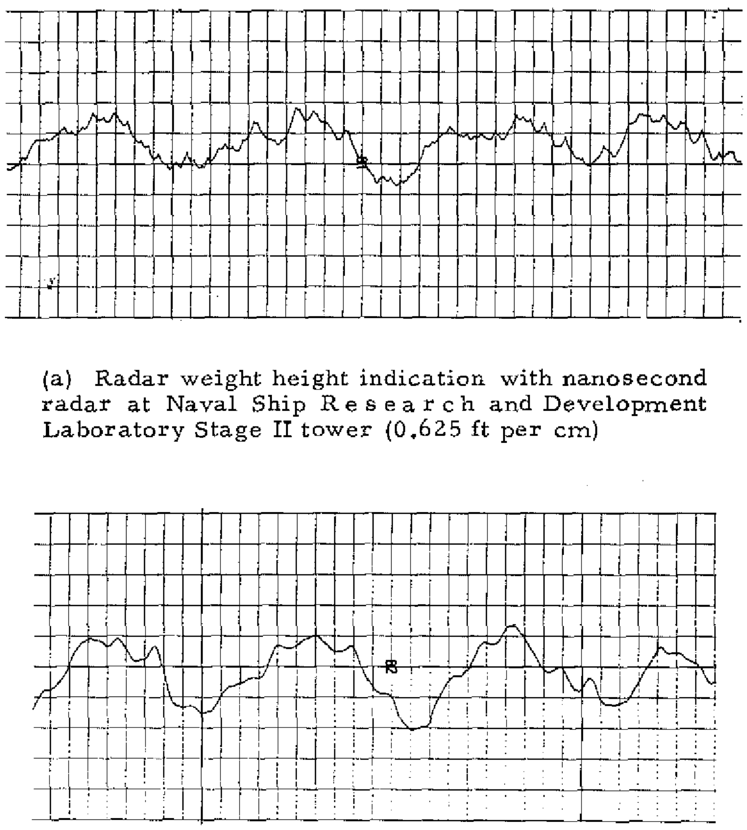


Fig. 7b - Dual antenna installation - top of Panama City tower



(a) Radar weight height indication with nanosecond radar at Naval Ship Research and Development Laboratory Stage II tower (0.625 ft per cm)

(b) Naval Ship and Research Development Laboratory, Panama City, wave gage output on Stage II tower (0.625 ft per cm)

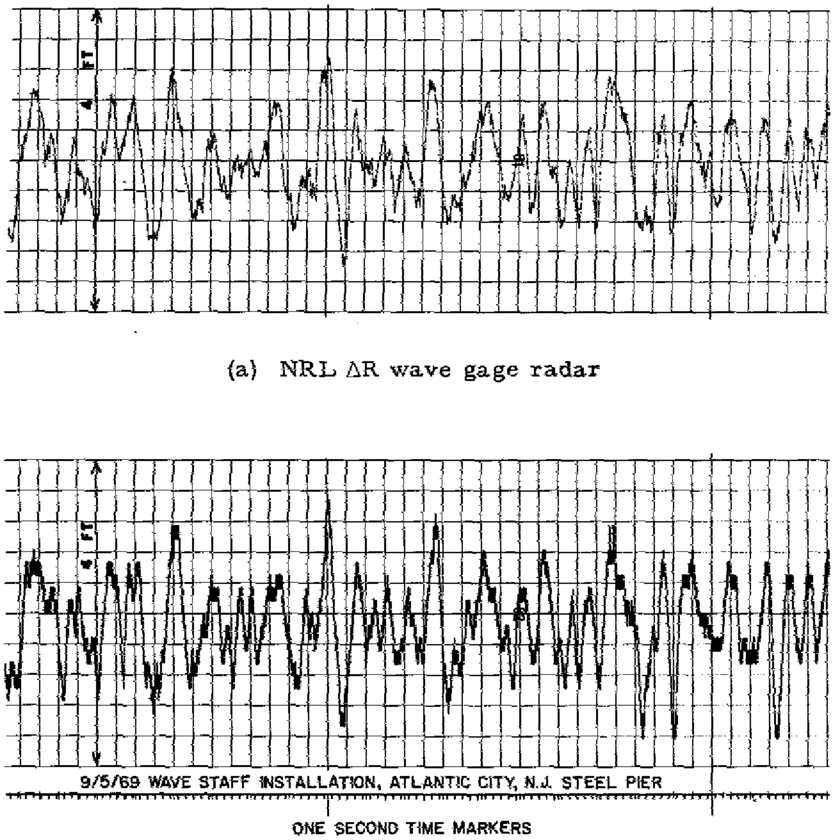
Fig. 8 - Comparison of radar wave height measurements to wave gage measurements

indicate that a flying wave-height sensor would not be too difficult to design, either integrating the wave variations to develop an average elevation value as a feedback signal to cancel out changes in elevation or using an inertial reference signal independent of fast range changes.

Atlantic City Tests

To evaluate this wave-height-measuring application of the NRL nanosecond-pulse radar for the Army Coastal Engineering Research Center (CERC), the radar was taken to their wave-staff installation on the Steel Pier in Atlantic City, New Jersey, for a two-day test. Their installation consists of three different models of wave sensors, a step gage, a Baylor gage, and a bottom-mounted pressure gage. Since this latter gage filtered out much of the roughness measured by the other two, no effort was made to compare the radar record with it. Figures 9 and 10 show the radar gage comparison with the step gage and with the Baylor gage.

The water was 17 ft deep at the end of the pier, the horn was mounted 24 ft above the surface, and the wind for these tests was estimated at 12 knots from the northeast. A 10-minute sample of the radar record was sent to their Washington record storage



(a) NRL ΔR wave gage radar

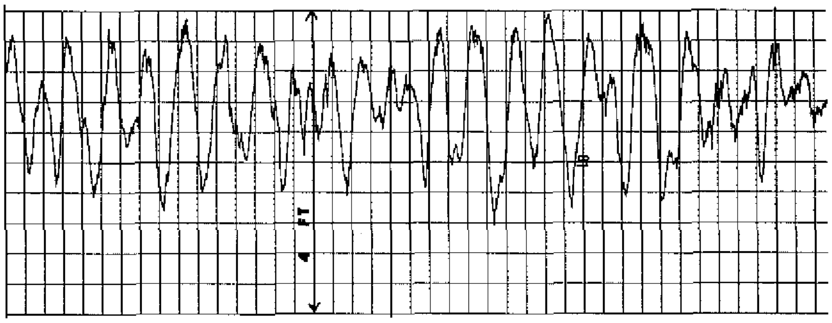
(b) Coastal Engineers Research Center 2-in. step wave gage

Fig. 9 - Simultaneous comparison of radar wave gage with staff step gage. The radar spot size was 2.5 ft, which was displaced laterally 5 ft from staff.

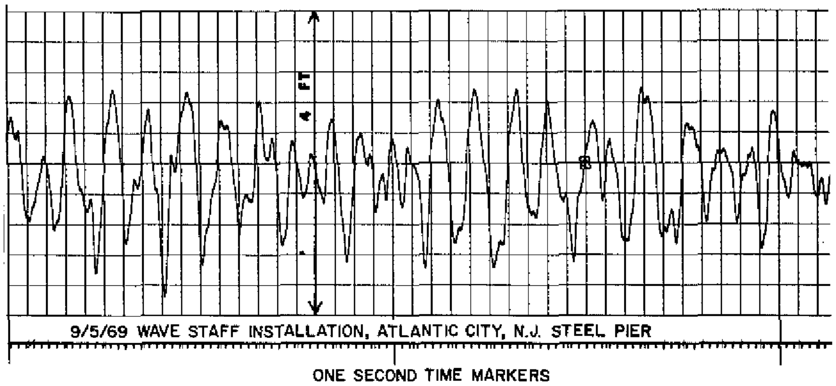
laboratory over their permanent line. A later check with them indicated that this record met all of their requirements; i.e., it had no "drop-outs" that plague laser gages, and it agreed with the patterns of their two wave staffs. Future tests are scheduled at our convenience when a programmed version of the test radar can be assembled and left on the pier to run around the clock, taking samples of wave height for 7 minutes out of each hour. The purpose of this test would be a final evaluation for CERC and the accumulation of statistical radar wave data for a wide variety of wave conditions.

RESULTS

The experiments have shown that periodic oscillatory range motion of a single echo in any "A" scope presentation (or the first echo appearing in that sweep) can be translated into a pen-recorded analog record by use of a simple ΔR circuit driven by the sampling scope sawtooth sweep output and the vertical amplifier output. The possibility of a pulsed radar giving a form of velocity measurement was noted when using the ΔR radar to study the swinging sphere target. When the moving sphere echo coincided in range with the echo from another nonmoving target, and the system was operated in the range-gated mode at the range of the fixed echo, a rapid flutter in the output occurs due to the "beating" of the two echo signals. From the speed of the paper recorder and the wavelength of the radar, the velocity of the swinging sphere at this range can be derived.



(a) NRL ΔR wave gage radar



(b) Coastal Engineers Research Center Baylor gage. The Baylor staff was of the two-wire capacitance type.

Fig. 10 - Simultaneous comparison of radar wave gage with Baylor gage. The radar spot size was 2.5 ft, which was displaced laterally 5 ft from staff.

Fixed-platform mounting of the ΔR test radar provides a simple means for accurate measurement of the gross pattern of ocean waves. This method involves sensing the elevation of an area rather than the intersection of the surface with a vertical wire, but with intelligent selection of the "patch" size the data obtained can be just as meaningful. The spot size chosen for most of the tests was 2.5 ft, and with the output unfiltered there was quite a bit of rapid "phase" flutter. Just enough filtering was added to match the filtering designed into the Baylor wave gage.

The brief helicopter-platform test did little more than indicate that the 10-milliwatt-peak-power battery-operated version of the ΔR test radar would operate without serious dropouts at the 100-ft elevation tested. The area included in the test flight covered waves from 1/2 to 2 ft, and the output record indicated up to 10-ft variation in elevation of the helicopter with approximately 1-ft waves superimposed on the slow elevation curve. An 18-inch parabola was used for a spot size approximately of 7.5 ft. More open-ocean experience is needed with this system to check ideal spot size and to experiment with methods of canceling out elevation changes in the record.

RECOMMENDATIONS

Several areas of interest to the Navy are suggested by this ΔR radar study. The demand for more accurate open-ocean wave-height reporting suggests continued effort in the helicopter platform testing. Slow-flying fixed-wing aircraft might also provide suitable platforms. With a suitable inertial reference system to cancel vertical motion of the bow, a ΔR radar could well measure the open-ocean wave heights if the antenna were boom-mounted in front of the ship. With several such sensors projecting from a carrier, prediction of ship pitch and roll underway would be feasible.

ACKNOWLEDGMENTS

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